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# Representing instructional design methods using ontologies and rules

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ABSTRACT

Instructional design theories are design theories that offer explicit guidance on how to help people to learn in specific situation. They can be used to guide the design of learning activities and the arrangement of associated resources. These theories are currently expressed in natural language, but they are often given some structure in terms of methods and conditions. Tools supporting theory-based instructional design require formal models of these theories to be expressed in languages with computational semantics, thus allowing their processing. Recent research has resulted in ontologies describing theory-neutral learning activity sequences and resources in accordance with proposed standards like IMS LD, but these are not sufficient for building instructional design aid tools. This paper describes the use of formal ontologies to partially represent instructional design methods in a form that can be used to build such supporting tools. Combining ontologies describing learning activities in a learning design with rules and constraints, it is possible to encode some forms of instructional design. This paper describes such an approach using OWL and SWRL. The approach has been evaluated by building a catalogue of instructional design methods expressed in these languages, obtained from a systematic extraction from a catalogue of instructional design theories. The practical utility of the ontological schema is demonstrated by means of a relevant case study.



## 1. Introduction

Diverse kinds of technologies have been used in e-learning, some aimed at supporting learners and others at supporting teachers and instructors. Regarding the former, support for students is reflected in efforts to improve the platforms and media used to achieve student learning by adapting them to their characteristics and learning needs [1]. Examples include *intelligent and adaptive learning systems* or *collaborative learning systems*. The latter use technology to give assistance to instructors in devising learning activities or resources, or in supporting the tutoring and assessment of learning experiences. In e-learning environments, teachers perform various activities [37] including the development and publishing of resources in repositories or Learning Management Systems platforms, thus helping students to solve problems and themselves to manage the learning process and assess student performance. To support these activities, several computer-supported techniques such as knowledge models [6], design tools [4], data mining [38] and intelligent systems [18] have been reported elsewhere.

The design of learning resources is an essential activity in instructional design. From the perspective of learning contents, these are presented using various media such as hypertext and multimedia (text, images, audio and video), usually structured with a view to producing reusable learning objects (LO) [11]. According to the IEEE LOM standard an LO is any digital or non-digital entity that can be used to learn, educate or teach. The ultimate goal of learning resources is to enable and enhance learning, but a large amount of these resources lack any defined instructional strategy, which causes many of them to fail in their goals [47].

The concept of Learning Design (LD) is defined as the application of instructional design knowledge to develop a unit of learning [25]. In another sense, "learning design" refers to the device resulting from the design process, i.e. the plan, learning resources, the ordering of activities and the tools required to carry out a particular learning experience [24]. The IMS LD specification permits the modelling of such learning process specifications. Through an IMS LD instance, resources, learning objectives, prerequisites, components such as roles, activities, environments consisting of LOs and services, methods, plays, acts and role-parts are specified and arranged. However, this specification does not allow the recording in digital form of the decisions or the instructional design methods used in the construction of an LD [41].

The construction of learning resources, more particularly of LDs, requires disciplined approaches. Instructional Engineering [32] is one method that uses a systematic approach to producing learning systems. Founded in Software Engineering, Knowledge Engineering

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and instructional design, it facilitates the systematic development of the resources by providing methods and tools which come from software development. It offers support for the management of development, i.e. it considers the method, its phases, its stages, its activities, its metrics and resources involved.

All these techniques can be used to support the design process. Instructional Engineering also uses methods from the field of education. An example of these are the Instructional Design Theories (IDT) methods which attempt to guide the designer in the construction of learning resources. According to Reigeluth [36], an IDT is a theory that offers explicit guidance on how to help people to learn. Some of these theories have been used to support resource development in e-learning [29]. Apparently, there is an ever-growing need in e-learning to use IDT to construct learning resources.

However, ID theories are currently expressed in natural language (in books, articles, etc.) and not in the sort of computational semantics that would make them usable when building intelligent computer tools. If representations were available written in computational semantics, they could be read by software.

Knowledge Engineering provides techniques of representation and knowledge acquisition that are useful for design purposes. From a broader perspective, it provides many artificial intelligence techniques such as model-based personalisation, intelligent systems and techniques based on ontologies and semantic web [39] More specifically, semantic web technologies can be used to build shareable knowledge models based on open standards such as the W3C OWL recommendation. According to Berners-Lee et al. [5], "the Semantic Web is an extension of the current web in which information has a well-defined meaning, more understandable by computers, and where people work cooperatively". In this sense, which encompasses technologies used in recent times, ontologies enable the meaning of things on the web to be defined better. They are designed so that this meaning can be processed by machines and humans on account of to their formal semantics [19]. The use of ontologies in the context of semantic web technologies is more oriented to delivering meaning to machines so that automatic systems can read and use that knowledge. Semantics are expressed through description logics. In this context, languages based on RDF have evolved in the last years, allowing for the sharing of ontologies. OWL, the ontology language recommended by the World Wide Web Consortium, exploits many of the capabilities of description logic, including a well-defined semantics and some techniques for practical reasoning. Another important language is SWRL (Semantic Web Rules Language) which enables rules to be defined for ontologies. It is a language which allows the description of the knowledge deductible from the ontological structure by reasoning about rules [7]. OWL allows to build hierarchies of concepts defined through a language of axioms, facilitates interpretation based on reasoning, describes concepts and relationships with other concepts. SWRL adds an additional layer of expressiveness which enables to define rules of inference to be defined in these models [30].

What motivates our research is the need to represent instructional theories in an interoperable and machine-understandable form for the practical purpose of building advanced instructional design tools. This paper presents an approach to the representation of methods of instructional design theories using semantic web technology. Using an ontology of the IMS LD standard as a base representation of the design outcomes, we specify representations in a computer-understandable form that can be used by theory-aware software. The approach followed consists in analysing each of the methods described as components of existing instructional design theories and expressing them in a combination of OWL and SWRL as far as is possible. In continuation of previous research [44], this work provides a complete catalogue following the general modelling directions already established. It also provides a first complete case study demonstrating the applicability of the approach for practical purposes in a domain in which mature domain ontologies are already in place.

The rest of this paper is structured as follows. Section 2 reviews such key aspects of the background to this research as instructional design, Educational Modelling Languages and ontological representations of IMS-LD specification. Section 3 explains the reasons for using ontological language to represent IDT methods. Section 4 presents the objectives, assumptions and approach used when modelling and also describes the definition of a rule-based catalogue of IDT methods. Section 5 then shows fragments of representations that are part of that catalogue. Section 6 presents a case study to demonstrate the usefulness of the catalogue. Finally, conclusions are drawn and scope for future work is suggested.

## 2. Background

This section describes aspects of instructional design, educational languages and IMS LD specification that are of importance to understanding the approach described in the paper. In addition, studies reporting ontological representations for IMS-LD are surveyed.

### 2.1. Instructional design

Instructional Design (ID) is the systematic application of theories and principles that guide the design of learning resources. IDTs help us to know how the body of knowledge is organised for use in the learning process [12]. The use of IDT offers guidance for the construction of learner resources by considering elements of the instructional context and the learner's learning goals. In contrast to learning theories, ID theories are prescriptive: they are oriented to design and identify methods and contexts of use [36]. Their methods can be broken down into sub-methods. ID methods are more probabilistic than deterministic, meaning that the use of none of them ensures the achievement of objectives, but rather increases the chances of achieving them. The situation of use refers to certain elements of context that influence the choice of methods, elements like instructional objectives and instructional conditions. According to the goals of this research, the characteristic of division into submethods becomes beneficial for the analysis and modelling of ID methods.

Reigeluth compiled numerous instructional design theories in "*Instructional-Design Theories and Models, Volume II: A new paradigm of Instructional Theory*", converting his work into a major source of knowledge about these theories, which include: Learning By Doing, Collaborative Problem Solving, Landamatics for Teaching General Methods of Thinking, Multiple Intelligences, Instructional Transaction theory and Elaboration theory.

Moreover, applying IDT methods requires a disciplined approach to indicating, for example, the sequence of activities and the results of each stage. Instructional design process models allow instructional systems to be created from a system perspective [28], covering stages ranging from analysis to implementation and evaluation. Some models propose a linear sequence for these activities, while other recommend models that consider iterations and incremental developments.

One of the most widely used ID model is ADDIE (Analysis, Design, Development, Implementation and Evaluation). ADDIE is regarded as a simplified model for learning resource construction [34]. Other examples of these methods are ASSURE [17], ARCS [20] and Dick et al. [9]. However, these models focus on phases and do not provide guidance to the designer when making decisions about whether a method is applicable in some context or give details of how to perform the activities.